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Military Medical Decision Support for Homeland Defense During Emergency

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14. ABSTRACT
This report describes the application of cognitive engineering methods to the design and analysis of a decision support system for training of command and control (C2) functions in emergency response organizations. The model is based on the principles of collaborative team planning and decision making that share a common interface designed to train cognitive tasks such as planning, information management, and synchronized task schedules. We demonstrate the application by designing and evaluating the Medical Emergency Response using Military Asset in an Integrated Decision Support (MERMAIDS) developed for training of emergency response teams using heterogeneous resources under a unified command and control. The MERMAIDS has been designed to contain a decision-centric interface, which is not only useful for emergency information management, but has decision models to support response planning during emergency conditions. An expert heuristic evaluation of the MERMAIDS is encouraging. The expert emergency C2 operators reacted favorably to the system, especially its application in planning emergency response under resource constraints.

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PREFACE

This report documents the results of a project conducted by The Institute for Human-Machine Studies at North Carolina A&T State University under U.S. Air Force Grant #F33615-03-1-6302. Mr. Edward Boyle and 1Lt Amy Turner, of AFRL/HEAL, were the Air Force technical monitors.

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SUMMARY

There are many threat elements that can potentially lead to medical emergency needs. They are (1) human, (2) biological, (3) nuclear/radiological, (4) incendiary, (5) chemical, (6) explosive, and (7) cyber attacks against information and data systems. Several civilian agencies may potentially collaborate with the military counterpart to respond to any threat situation. These agencies may be comprised of (1) fire departments, (2) police departments, (3) medical and public health organizations, (4) public works organizations, (5) public and private utilities, and (6) private sector humanitarian agencies (e.g., Red Cross).

An emergency command and control (C2) structure is designed to respond to differently and varying dimensions of emergency situations. In today's threat prone environment, each of the command hierarchies is likely to consist of military and civilian agencies during an emergency response situation. Within the team composition above includes: (1) individuals who communicate and act on the basis of their individual command structure and organizational doctrines. Thus, each group bring to the emergency team, multiple strategies and viewpoints to incident response ; (2) distinct cultural norms for organizing; (3) distinct human procedures, policies, and routines for coordinating information and decision-making; and (4) a unique ensemble of resources such as laptops, mobile phones, sensors, and handheld devices to manage and communicate information.

Simulation modeling used for training of a coalition of multi-agent emergency workers is presently limited because no single constructive modeling support tool can represent all aspects of the contextual variables. For example, in a typical emergency situation, interacting activities might include traffic flow, hazardous cloud movement, positioning of emergency personnel, fire simulation, damaged structure analysis, etc. For this reason emergency response management (ERM) models capable of supporting and focusing on specific realities such as a terrorist attack, require extensive time to be developed. Integrating technology into an operational context poses yet another challenge.

To address this concern, this project develops a prototype, proof-of-concept, and scalable decision support simulation for training emergency C2 staff. The product of this research is a software system known the ***Medical Emergency Response*** using ***Military Asset in an Integrated Decision Support (MERMAIDS)***. This report summarizes the result of this research. Specifically, the report is structured into four chapters:

- Chapter 1 provides the background of the problem addressed, including the project scope and anecdotal related past studies.
- Chapter 2 presents an approach to designing a decision support for emergency C2 information management. The Chapter highlights the cognitive systems engineering tools—cognitive task analysis, Rasmussen's abstraction hierarchy, Vicente's work domain analysis, and the OFM (operator function model) of Jones and Mitchell, respectively. By using the abstraction hierarchy, three levels of information requirement for designing emergency training interface are recognized. These are epistemological requirement which help to convey meanings of task situations, ontological requirement which provide the mechanism needed to organize information

representation for user interface design, and ontological requirement which is used to elaborate how the emergency C2 information is shared across organizational hierarchy boundaries.

- Chapter 3 contains the theory and methods of decision-centric user interface for emergency decision support software design. It is assumed that the human-computer interface (HCI) design for emergency C2 center should be a highly mutable construct, adapting both to the human concepts of tasks and the standard operating procedures available to each of the emergency task scenarios. Thus, such an interface design that support human decision making process is considered to be decision-centric. A typical decision-centric interface is supported by at least four design principles. The first is based on the principle of verification which is used to ascertain the efficacy of the embedded knowledge representation in the interface artifacts. The second principle is based on Norman's four-tier stages of intention, selection, execution, and evaluation. The third principle is based on collaborative work support and team performance which advocates shared mental models through good situation awareness. And, the forth principle is based on embedded cognition which advocates that the interface widgets should embody both the task and human cognition in context. By adopting these principles, the MERMAIDS system is designed to recognize both the semantic and syntactic relevance of the tasks within the user's cognitive space.
- Chapter 4 presents the conclusion and suggestions for future research in this area. Specifically, it is recommended that the MERMAIDS model should be expanded to include:
    - Adding Global Position System (GPS) for real-time travel advisor
    - Virtual reality modeling or graphical animation of crowds in the crisis sites
    - Extending the current static databases to accommodate variable information capture
    - Expanding the MERMAIDS model to handle training for multiple crisis response situations
    - Using MERMAIDS for multiple team planning
    - Conducting experiments to validate effects of emergency team composition on emergency response performance.

TABLE OF CONTENTS

LISTOF FIGURES

LISTOF TABLES

CHAPTER 1: PROLEGEMA

INTRODUCTION

After the deadly incident of September 11, 2001, the U.S. government has determined never to be so unprepared during unexpected national or local disasters that may be orchestrated by terrorists or natural disasters. While the devastation was on a scale rarely witnessed, the weaknesses in the emergency-response system that emerged, as events unfolded, are endemic to emergency-response systems across the United States. A critical shortcoming was the lack of an integrated, reliable system for sharing data and communication among all of the agencies involved (Dwyer, Flynn, and Fessenden, 2002).

Unfortunately, the level of effects usually demands medical attention in an unprecedented proportion. For example, a terrorist attack with biochemical weapons may lead to epidemics that require massive relocation and treatment of large population with a time constraint. Thus, resources and support personnel tasked for such emergency response situation should maintain a comfortable availability threshold, including, adequate training of the personnel.

Dealing effectively with disasters requires, among several things, a coordinated planning and preparedness support model that can be used to coordinate command and control, training, resource planning, logistics, and scheduling. It is coordinated in the sense that multiple agents are involved—military and civilian organizations (Police, Red Cross, Paramedics, and so on).

Research in emergency response management has grown significantly since the terrorist attack on the World Trade Center on September 11, 2001. Most of the research interest is on training and the development of computer-based decision support systems. Perrow (2003, p. 23) observes that "a substantial literature on disasters over the last 35 years has shown that for natural, industrial, and most recently the deliberate disaster of September 11, planning and rehearsal by authorities at the local level (fire, police, medical facilities) makes a large difference in the effectiveness of the response." Training at the emergency response command and control (C2) centers are therefore important to improving field response effectiveness (Balogun, Ntuen, and Boyd, 2004).

The primary goal of emergency response training is to provide first responders with their first experience of virtually any emergency situation they might encounter. Training exercises ensure that when confronted with real emergencies, responders will be able to invoke these pictures (and the accompanying protocols) rather than confront a first-time situation for which they have only theoretical knowledge of the protocols (Jevald, Morin, and Kincaid, 2001).

Today's emergency management offers varied challenges to the emergency response team (ERT). For example, complex and interrelated plans from different command and control (C2) agents must be developed and executed in real-time, limited resources must be carefully managed and coordinated, and time-critical, high-stake decisions must be made.

Generally, the ERT operators are exposed to solving problems in a complex and uncertain information space. To support the ERT personnel, information resources and data must be quickly and efficiently processed and analyzed, and then formatted and presented to fully support critical decisions. These tasks are better performed by computers. These functions are the core training modules required for the development of emergency decision support systems (DSS).

Emergency training functions are increasingly complex as more heterogeneous teams with diverse training backgrounds are required to work together. With the increasing requirement for team and multiple agencies to respond to emergencies, there is a growing recognition that the mode of operation of C2 in emergency and disaster relief organizations must change to accommodate the characteristics of team decision making (Pidd, De Silva, and Eglese, 1996). Also the cultural differences in standard operating procedures, organizational design, and task differences have important implications for emergency C2 effectiveness. Issues such as how people of diverse languages, military and political doctrines, and standard operating procedure differences affect courses of action (COA) planning remain an important research issue for emergency management systems.

THE PROJECT SCOPE

The fundamental premise of this project report is that managing a single- or multiple- tier emergency planning with either heterogeneous or homogenous resources will require a decision support system (DSS) to support training and planning of command and control (C2) functions. The DSS should be designed to ensure that its multi-layered representation of individual and organizational procedures, practices, databases, computational aids, and other logistical resources are coordinated into an ad-hoc semi-automated decision support system, verified, and reconfigured to provide a continuous training and decision support for the responsible people involved. The DSS must also exhibit quality usability metric with the ability to process and manage heterogeneous information in real-time. Therefore, the scope of this report is limited to developing a prototype human-computer environment with embedded decision aids to support a heterogeneous team of medical emergency response agents. Specifically, this phase of research emphasizes computer modeling of emergency response team decision-making based on diverse organizational policies and standard operating procedures (SOPs). The product of this research is a software system known the ***Medical Emergency Response*** using ***Military Asset in an Integrated Decision Support (MERMAIDS)***. The MERMAIDS functionality has been experimentally validated for usability.

SELECTED PAST STUDIES

Most of the existing decision support systems for emergency management are based on restricted context applications and ad hoc simulation techniques. Some examples include, EXITT (Levin, 1987) and BFIRES-II (Stahl, 1982) for residential fires management, and ROSES (Briano, Orsoni, and Viazzo, 2002) for modeling the phenomena of oil spills in sea considering; and CATS (Consequences Assessment Tool Set; 2000) that combines the state-of-the-art hazard and consequence prediction to provide significant assistance in emergency training, including, exercises, contingency planning, logistical planning, and calculating requirements for humanitarian aid. Mendonca, Beroggi, and Wallace (2001) have developed a conceptual decision support model for improvisation in emergency management. The concept is based on the paradigm of operational risk management and is motivated by the observation that emergency response organizations must be prepared to improvise during response activities. Buzolic, Mladineo, and Knezic (2002) developed an experimental software system known as DPPI (Disaster Preparation and Prevention Initiative) for telecommunications and information support during emergency situations.

The common thread in the decision-support systems cited above is the lack of a computer interface that allows users the access to the right information in the right context and time. This project presents the development of human-computer interface to support the training of emergency response team personnel at the emergency C2 center.

CHAPTER 2: AN APPROACH TO DESIGNING DECISION SUPPORT SYSTEMS (DSS) FOR EMERGENCY C2 INFORMATION MANAGEMENT

SUPPORTING MODELS

Decision support systems are computer models designed to help or support humans perform their tasks, such as decision making, in complex domains. Emergency poses various characteristics that are not only complex, but complicated and chaotic. The most recent example is the Tsunamis disaster in Asia. Here, the emergency C2 staff was tasked to deal with complicated tasks of combining and coordinating probabilistic information, responding to not only medical and food relief, but also to the psychological trauma induced by the stress of homelessness and loss of lives. Enactment tools to support a coalition of international decision makers are vital.

Designing a DSS for emergency domain requires a human-centered approach. Human-centered design systems make use of cognitive systems engineering (CSE) processes, which attempts to integrate the conceptual and computational framework of human cognition. As noted by Jones and Mitchell (2002), "Cognitive engineering is the rigorous and contextual study of human-machine interaction in complex systems and the design of artifacts that enhance system performance by enhancing human performance (pp. 2)".

The conceptual framework of CSE is derived from the context of tasks and work domain analysis (Vincent and Rasmussen, 1992), and is a function of applied cognition in situated tasks. For example, take a simple car accident, the description of cognition in context here leads to knowledge acquisition about the cause and effect of the accident, the protocols for providing relief to the victims involved, transportation to hospital (if necessary) and so on. Thus, even in a simple incident as the car example, there is an enormous task of information collection, analysis, and decision making relevant to the context of the task.

The computational framework of CSE provides the ontology for human-computer interface (HCI) design that can address issues of context tasks and work domain analysis concurrently. The HCI, therefore, represents the artifacts of human cognition and the tasks. The computer models allow us to simulate the human actions and the representation of the behaviors of the world around us, particularly, the worlds that represent situated actions, user roles, data roles, and other characteristics that interact with space and time.

Cognitive Engineering

As noted by Norman (1990) the aims of cognitive engineering are first, "to understand the fundamental principles behind human action and performance that are relevant for the development of engineering principles of design and second, to devise systems that are pleasant to use (p.32)". This definition has engendered many psychological and design studies specifically in human-computer interaction and recently in designing team decision aiding and training systems (Jones and Mitchell, 1995). Cognitive system engineering (CSE) is about the integration of human knowledge about task (environment and perception), cognition, and artifact behaviors that can lead to the execution and control of specific tasks at various levels of abstractions (McBride, Adams, Ntuen, and Mazeva, 2004). CSE has the capability to capture the human procedural-, operational-, and structural- knowledge about events, activities, and behaviors as reasoned through human actions (Zarakovsky, 2004). These provide the main source of knowledge for design of cognitive aids, especially those used in training (Bedny and Meister, 1997). The knowledge required for training can vary along a discrete continuum of the operator's level of expertise, psychological states and traits, and task dimensions (Quarantelli, 1997). From the CSE perspective, the level of expertise is commonly assessed along the dimensions of skill-, rule-, and knowledge-based behaviors known to control the decision-making ability of the human operator (Rasmussen, 1996). Implicitly, the levels of expertise allow us to replicate human mental model of a system with a computer.

The core of CSE practice lies on cognitive task analysis (CTA). CTA serves as a knowledge acquisition tool for collecting human knowledge about the system of interest (Gott, 1994). To accomplish information acquisition for emergency training model design, CTA was used to acquire and represent the necessary information processing processes between C2 center operators and the field responders. This involves, decomposing emergency tasks into subtasks, skills, and knowledge requirements by the C2 operators. Because CTA often emphasized the role of expertise (Rasmussen, 1983), highly trained emergency response professionals were used to gather information on the methods, processes, and operations used in different types of emergencies.

THE THREE LEVELS OF INFORMATION REQUIREMENT FOR DESIGNING EMERGENCY TRAINING INTERFACE

Understanding the emergency C2 training objectives is the first component of the decision support system (DSS) design ontology. Next, the decision support modules must be designed with human-computer interface components that support not only usability, but serves as an expert advisor to the users. The basis for achieving this is the application of information abstractions recognized at three levels: the knowledge components or epistemology levels, the design components or design ontology levels, and conceptual components or notional formalisms levels, respectively. These three information levels constitute the basic framework for designing human-computer interface (HCI) to support the emergency training DSS.

HCI is a body of knowledge dealing with design of software and hardware tools to support human interaction with automation (Shneiderman, 1998). HCI affords the users with interaction and communication facilities during information processing tasks at multidimensional levels, including, for example, physical, social, and psychological levels. This stance has forced researchers to try to understand the user, the work system and organization, the nature of information technology, and the capability of computers (Croft, 1984). Coupled with these requirements is the nature of information levels mentioned above. A brief discussion of these three stages as they relate to emergency DSS is presented next.

Epistemological Requirement

Epistemology is the study of knowledge and its meaning in context (Notturno, 1993) and is often viewed from several dimensions of human cognitive processes—abstraction, reasoning, and inference. As a tool, epistemology has been used to design HCI systems so as to help convey meaning of objects and entities in context of task to the user (Sterling, 1974). In terms of information processing about the context of interest, knowledge representation in the HCI system must be able to address the user's prejudices, myths, beliefs, and superstitions about the phenomenon of discourse. For example, an emergency of crisis proportion such as that witnessed on September 11, 2001 at the World Trade Center in New York continues to beg for epistemological inquiries on such issues as why it happened, how it happened, and what were the causes. Answers to these inquiries provide useful information to understanding and modeling of emergency situations. It can also reveal salient information on, say, terrorist groups, that include, but not limited to the reliability of terrorist information, location, person or persons, cultural affiliations, and so on.

Ontological Information Requirement

As used here, ontology provides the mechanism needed to organize the requirements and representation of information about emergency tasks. It provides the rules about what the computer agents should do and what human operators should do. The HCI for supporting a team of emergency C2 workers must embody a design philosophy that provides for explicit support to the user with respect to syntactic as well as semantic contents of information required by ERT operators. In order to achieve this purpose, the ontological issues are used in the study as follows:

(a). Information characteristics which contain the necessary attributes required by the C2 center personnel. These characteristics include the type of incident, level of emergency response desired, originating source of the incident, time of incident occurrence, the suspected causes of the incident, and the location of incident.

(b). Information representation which is driven by the ontology about how the emergency information is stored in the computer database. Here, the method for information representation adopted is based on schema ontology (Geiselman and Samet, 1980). Geiselman and Samet (1980) noted that a schema constitutes the basis for "categorization, selection, deletion, abstraction, consolidation, and organization of information in the memory". Each schema holds a specific knowledge or data category in a slot or slots. Information in the slot is analogous to a particular level of abstraction. In the emergency DSS, a schema is used as a method for knowledge representation based on grouping of crisis information attributes based on space and time. Barlett's (1932) concept of a schema as a relational structure of information concepts across abstraction boundaries was used as the knowledge representation mechanism. Hintzman (1976) identified three types of schemata that were evaluated to be appropriate for the design representation of emergency training DSS. These are functional, cognitive, and conceptual. In our model, the functional schema contains information on the functional roles of C2 and the field emergency personnel. And, the cognitive schema contains quasi-analytic algorithms and rules about emergency planning. The conceptual schema contains information about notional response and procedures required for any incumbent crisis conditions.

(c). Information processing between human and computer artifacts, which considers the five level of Sheridan's supervisory control paradigm (2002). The supervisory control model embodies planning, teaching, monitoring, learning, and intervening. At the planning level, the DSS supports the ERT personnel with the procedures for developing strategic plans appropriate for the crisis at hand. The teaching module consists of methods and procedures used by emergency crews. These are programmed as computer codes, and include such tasks as, crisis response planning, resources allocation algorithms, route planning used by ERT members to the destination of incident, weather information, and triage planning advisor for on-site medical relief for victims. The monitoring process module supports continuous task management and has

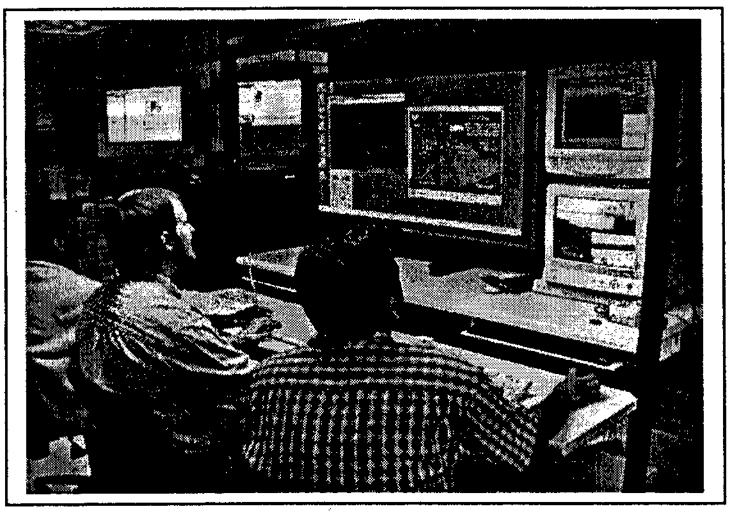

Figure 1. Sample C2 center for emergency operation.

modules with information display and visualization (see Figure 1). During the monitoring task, the C2 center personnel are engaged in a continuous review of map for events using display technology systems. Display and visualization supports dynamic situation awareness since field activities as well receiving information updates from the field workers and supervisory headquarter staffs can be performed concurrently. The intervening module allows the human operators to preempt and change decisions made by the computer aids, or re-allocate resources to new emergency conditions.

(d). Information display and visualization module which allows C2 staff to view system states and updates using maps, graphics, video cameras, and weather conditions based on the methods of ecotopic displays (Ntuen, 1998). In the ecotopic display model, information is presented to the user based on a defined context (using enunciator to mimic the incident warning system such as adopted by the Department of Homeland Security), or through a menu selection by the C2 operator. The ecotopic display model uses a situation awareness model to predict the next state of the information requirements and dynamically allocates display resources to support information seeking by the human C2 operators (Endsley, 1995).

Notional Information Requirement

Here, we model the granular levels of information abstraction based on the organizational design. For example, information abstraction in a coalition of military and civilian emergency response team (e.g. September 11, 2001 incident of World Trade Center) is different from say, a simple ad hoc information requirement for a car accident emergency response. The support for notional information taxonomy is described in terms of cognitive abstraction hierarchy (Rasmussen, 1996). Based on the emergency organizational hierarchy, an information token for an event is represented as a notional artifact that has the capability to recognize the history of requests for that hierarchy, as well as, how other hierarchies in the stream of information processing share information. The notional information representation also allows for seamless knowledge mapping across hierarchical boundaries in the abstraction hierarchy. This topology, in turn, can then be compared with a set of operational issues emerging from one emergency mission to another, so as to identify relevant opportunities for immediate decision making. Table 1 shows an example notional qualitative information analysis used to capture the interactions across organizational design hierarchies as a mix of simple to complex command and control tasks arise.

Table 1. Single command, single point of control, multiple commands, multiple point of control.

	Single control point	Multiple control point
Single command	A single agency is responsible for crisis management leadership; the control elements reside primarily on this agency. For example, the firefighter is usually responsible for a rescue operation for burning buildings.	A single agency is responsible for command for a coalition or a joint task force. For example, a firefighter agency selected to be responsible for emergency rescue of a relief operation involving other agencies such the police, Red Cross, and / or military.
Multiple command	Different agencies are responsible for emergency relief efforts, but control lies with the respective agency. However, a common metric of performance is established across the agencies.	Here, multiple organizations are tasked to manage many collateral emergency problems. An example includes many relief agencies and nations responding to earthquake incidents requiring medical support, habitation relief, food supply relief, etc.

CHAPTER 3: DECISION-CENTRIC USER INTERFACE FOR EMERGENCY TRAINING DSS

A THEORY OF DECISION-CENTRIC INTERFACE SYSTEMS

Computer-supported human decision-making performance in critical situations is dramatically affected by design factors that include decision aiding for the human operator. In the emergency response tasks, the decision requirements comprise of diverse and multiple information sources that must be integrated to support the crisis first responders. The C2 staff must be supported to make good decisions about how to plan and response to incidents. The C2 staff must also monitor and interpret environmental and situation data to make judgments about incident status and decisions about the kind of response. The human-computer interface (HCI), designed to support the C2 staff should therefore, be a highly mutable construct, adapting both to the human concept of the tasks and the critical incidence information to support the human decision makers. Interface designs that support the human decision making process is considered here to be decision-centric, which in addition to the ability to display information to the user in an intelligible manner, can also make suggestions and critique the user's planning process (Silverman, 1992).

Supporting decision-centric interface is based on at least four design principles. The first is based on the principle of verification. Under this principle, HCI has used cognitive models successfully in at least two ways. The first way is to help examine the efficacy of different designs by using cognitive models to predict task performance times. The Goals, Operators, Methods, and Selection (GOMS) method of techniques (Card, Moran, & Newell, 1983) particularly has been successfully deployed. The second way is by using cognitive models to provide assistance such as with embedded agents. In particular, cognitive models can be used to modify interaction to help users with their tasks. This technique has been employed in cognitive tutors (Epstein and Hillegeist, 1990). A number of cognitive issues related to HCI, for example, understanding of reasoning and decision making processes, often remain separated from the user interface.

The second principle is according to Norman (1984) who advocates representing information to the user in correlated four-tier stages. These stages are intention, selection, execution, and evaluation. As a rescue team or an individual rescue worker interacts with the HCI model these four stages of information processing are realized. In a rescue effort, for example, the major intent of a rescue team is to save as many lives as possible if an emergency occurs. The selection stage is when a team turns the intention into the action necessary to perform intentional activities (Dennett, 1971). During this stage in an emergency situation, the type of emergency is classified and the relevant rescue teams are assigned to perform the relevant actions. The third stage is execution. Execution is simply following through with the selected task. An example of the execution stage is a rescue team such as the paramedics going to a disaster area and tending to victims who are injured that needs to be treated and dismissed on the scene or transported to a hospital. Evaluation, the fourth stage, occurs during the after-action report that provides feedbacks to the C2 operation center.

The third principle is based on collaborative work support and team performance, which advocates shared mental model and situation awareness (Alavi, 1994). Here, a user interface designed for ERT tasks, must provide an environment for knowledge sharing, collaborative planning and decision making. The fourth principle is attributed to Sutcllife and McDermott (1991), which advocates embedded cognition as the basis for decision-centric interface design. By using the embedded cognition concept, a decision-centric interface is designed to represent the cognitive tasks often performed by the humans, and are designed so that the cognitive load by the human operator is minimized. In our design, the cognitive elements are embedded in the interface widgets. This allows the interface to support the execution of cognitive tasks without incurring excess costs such as errors, increased search times, and knowing where and when information is relevant to a context. In addition, a decision-centric interface is designed to support the user in the decision-making process, particularly, tasks that involve uncertainty in which the human cognitive ability is limited (Lee and Sanquist, 2000). Examples of such tasks include, but are not limited to, planning emergency response to multiple emergency crisis, determining the number of emergency room resources, and determining sources and potential spread of fire so as to plan deterrents.

By adopting the above definitions, the components of knowledge within decision-centric interface (DCI) are designed to allow the user to recognize both semantic and syntactic relevance of tasks within a cognitive space, including the relative importance of the information to task execution. The syntax-semantics model of the task provides the framework for thinking about how the user performs a task and the levels of granularity in which the user's cognitive dimension encounters task processing bottlenecks. Figure 2 gives a simplified architecture of a decision-centric user interface.

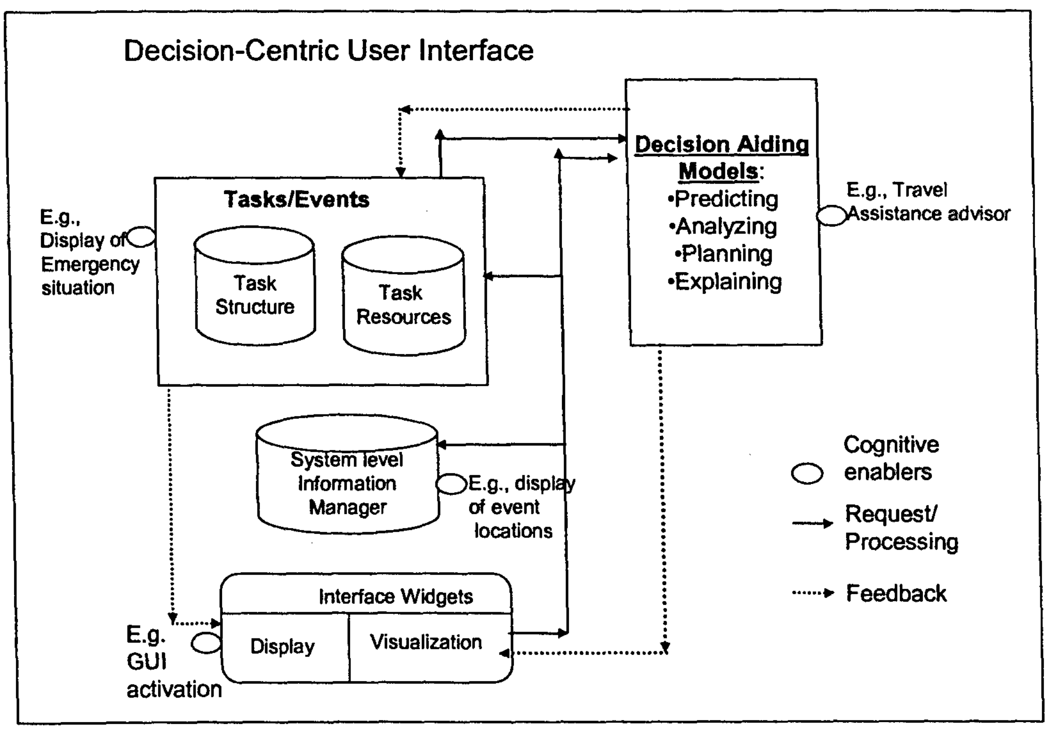

Figure 2. Sample architecture of decision-centric user interface.

The major elements of Figure 2 are:

- The Interface Widget: This allows direct manipulation (Shneiderman, 1993), including tools for display and visualization of information.
- System Level Information Manager: This contains databases that describe information on the incident characteristics. For example, incident location, class and types of incidents, history of previous occurrences, and so forth.
- Task or Event Description: This has databases used to describe the task structures and resources required for task performance. The task structure suggests the level of crisis and is used to trigger the type of resources and actions required.
- Decision Aiding Models: These contain home breed algorithms and techniques designed to support the user on incident analysis. For example, in the emergency domain, the travel advisor will advise the emergency field operators on the shortest distant to the location of incidents, the scenario advisor will display weather and terrain information, and so forth. Note that the small circles besides each information block are used to denote the cognitive enablers provided by the DSS through the abstract elements of the interface organizers or widgets.

THE DECSION SUPPORT SYSTEM AND INTERFACE FOR TRAINING EMERGENCY C2 PERSONNEL

General Description

Emergency management offers varied challenges reminiscence of a team or group. For example, complex and interrelated plans must be developed and executed using heterogeneous resources with different operating C2. As a time-critical task, ERT activities must be carefully planned. This requires training of the so-called "First Responders". To support this task, a decision support tool embellished with intelligent interface is necessary. The DSS contains models that address issues relevant to team planning using a variety of response agents: firemen, police, paramedics, Red Cross, and military.

The decision support system and the embedded interface system developed for this project is known as Medical Emergency Response using Military Asset in an Integrated Decision Support (MERMAIDS). The decision support models in the MERMAIDS describe team performance using constructive simulation experiments of medical emergency planning conditions that require a heterogeneous team of military and civilian emergency personnel: Air Force Aeromedical units, Navy and Army medical units, Red Cross, Firefighters, Emergency Medical Response, Police, Federal Emergency Management Administration, etc. It is assumed that the team is under a single C2 agency such as the Department of Homeland Security who can call upon any of the supporting agencies to respond to emergency situations.

The understanding of ERT tasks requires both the behaviors used in performing the tasks as well as the team mental model used in courses of action planning. To accomplish information acquisition for model design, a cognitive task analysis is used as a tool (Gott, 1994) and the computational knowledge representation achieved by using the operator function model

(OFM). The OFM is a framework for modeling cognitive processes in a dynamic system with the effective realization of computational representation (Jones and Mitchell, 1995). The OFM allows for mathematical representation of human-system behaviors based on state transitions mitigated by task allocation and function requirements. The OFM is a network in which nodes represents operator activities. Activities are structured hierarchically and represent operator goals or functions at the highest level but individual actions at the lowest level. Actions may be physical or cognitive. The OFM provides a means to structure and organize observed behaviors, permitting the abstraction of information based on the hierarchy of activity groupings. Figure 3 shows an illustration for emergency C2 information modeling in which the major tasks are illustrated by the rectangle bars that consist of C2 functions, monitoring, emergency tasks and activities. The oval shapes contain information on low level activities and actions.

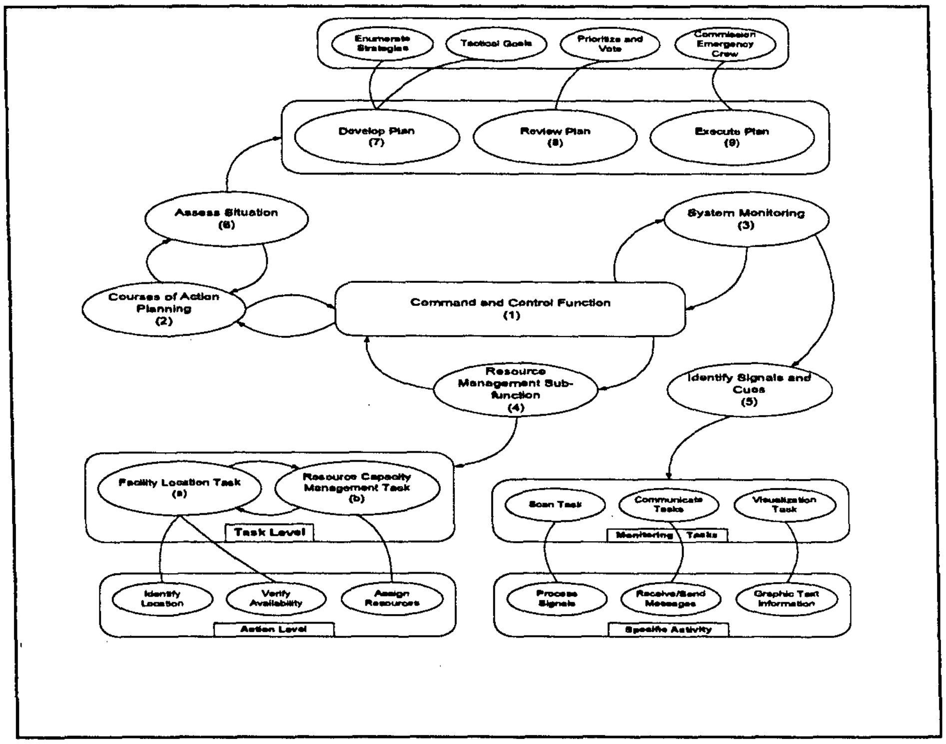

Figure 3. Sample OFM for emergency C2 information modeling.

One aspect of an OFM for the MERMAIDS is shown in Figure 4, the ERT tasks can be decomposed into three abstract information processing levels. Level 1 contains information flow and linkages at the C2 center. The C2 center staff is responsible for monitoring the environment and taking calls related to incidents. The staff is also responsible for courses of action planning. The staff has a mix of various skill levels as typified by Rasmussen's (1983) skill-, rules-, and knowledge- behavior taxonomy. Level 2 represents C2 information management. Example tasks include, in our case, the READ (Resources for Emergency Assignment and Distribution) model. The READ model contains a database of resources with capacity, equipment, and capability profiles. The third level contains information for task execution and monitoring, including type of tasks, information support such as the travel advisor to the off-site emergency personnel, and tasks performed on-site of the incident.

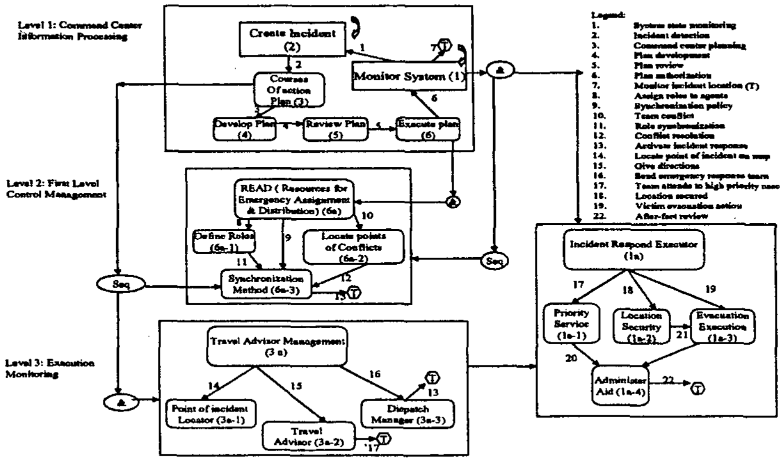

Figure 4. An OFM representation of the computational view of emergency information processing.

Decision Support Components

The decision support components of the MERMAIDS are designed to take the advantage of the independent and diverse organizational standard operating policies (SOPs) existing within the civilian and military C2 emergency response elements. The MERMAIDS system is useful in presenting emergency planning scenarios at various levels of information complexity as manifested in emergency courses of action (COA) planning, analysis, and execution. The MERMAIDS system also supports a team of decision makers who are geographically co-located or dispersed to have access to plug and play emergency COA planning simulation scenarios, while performance is observed in real-time by the computer agent.

Figure 5 shows an example MERMAIDS screen for C2 center information management. In Figure 5, there are incident severity codes similar to those employed by the Department of Homeland Security. The red and green rectangles on the right side show the location of emergency response facilities, in this case, fire and paramedics.

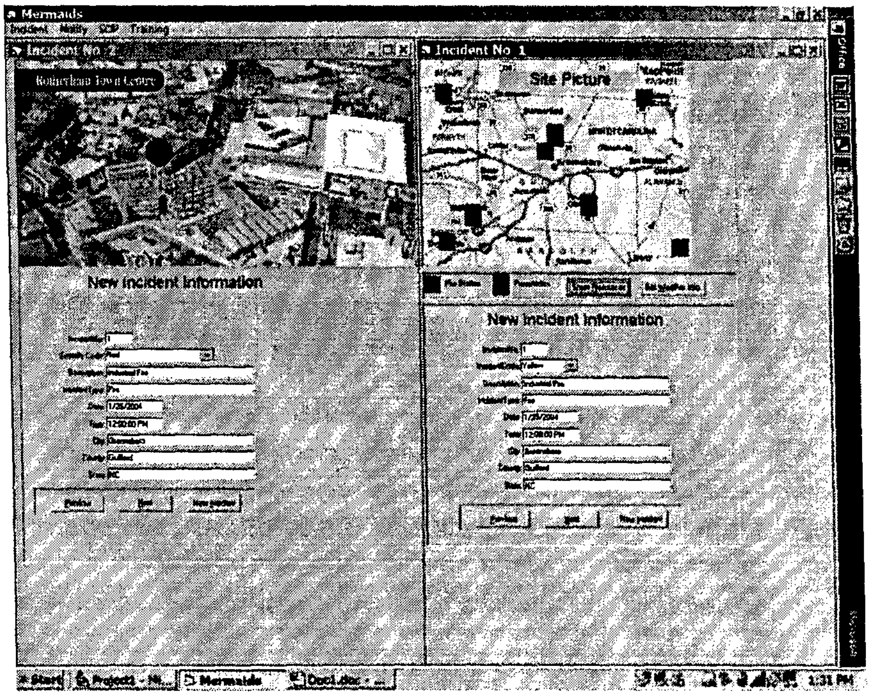

Figure 5. Sample MERMAIDS screen with incident map (right side) and incident aerial photograph (left side).

Specialty Information Agents in the MERMAIDS Interface

The interface in the MERMAIDS is designed to take advantage of collaborative teams. For this reason, the interface has specialty agents for the following tasks:

Supporting Multi-agency Planning Protocols

An important element in any effective rapid-response effort is the quick formation of C2 plans, coordinating the efforts among multiple agencies, and then guiding the responders by letting them improvise a plan constructed on-site based on the emergency situation and the prepared protocol (Mondschein, 1994). Two model examples in the MERMAIDS is the travel advisor which displays maps as well as instructions from location of resources to the incident site, and the Internet and Web information systems to support real-time distributive communication between emergency workers.

Training a Coalition of Decision Makers

Training is provided to the first emergency responders to enhance the use the individual and group 'know-how' and 'know-what' knowledge about situated actions. The MERMAIDS training module can be assessed through the Web. The training modules are built from varieties of emergency response organizational doctrines, standard operating procedures, and requirements for specific tasks. The training module has lessons for localized contexts and general contexts. Localized contexts are for isolated, small-scale emergencies such as minor car incidents. Generalized contexts encompass emergency response of global dimension such earthquakes, terrorist attacks, and other relief incidents that may require a joint task force or a coalition of emergency relief workers. Figure 6 shows a sample screen for the training modules.

Unified Command Center Information Management
The MERMAIDS has established C2 at three interacting levels: (1) Local Incident Command representing the first-response personnel from one or more agencies, (2) Unified Interagency Command for direction and synchronization of the interagency operations, and (3) Emergency Operations C2 center to support policy decisions. Emergency responders must cooperate jointly as part of an interagency response since no single agency has the ability to respond to a catastrophic event. The information coordination challenges include the dissemination of threat response advisories to all participating agencies and to the public, as well as the synchronization of information received from the field responders.

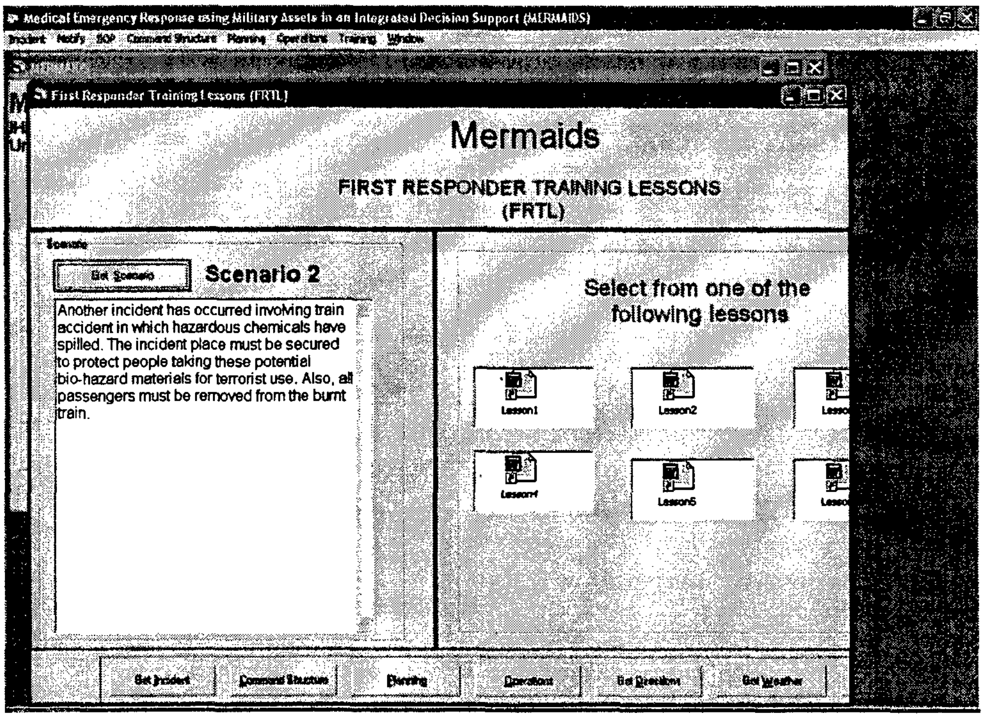

Figure 6. Sample MERMAID screen used for training.

Knowledge Management
Knowledge management in the MERMAIDS planning contains modules for mission management, incident management, resource management, and a dynamic information processor which operates using random access information warehouse embedded in the display and visualization models. The information warehouse has legacy databases of past emergency events and their response plans. The information warehouse also allows the user to conduct real-time data mining and information retrieval needed for any emergency condition.

Situation Awareness Model
The MERMAIDS contains normative-descriptive models for team situation awareness and team mental models using maps and other display information to mitigate common operating pictures by C2 center and field operators. Situation awareness model enables the users to visualize information so as to enable real-time prediction of the system states in time and space (Endsley, 1995).

Analytic Decision Aiding
The MERMAIDS contains decision aiding models designed to provide real-time support to the emergency personnel working in teams, as well as metrics for measuring human operator performance. These include, a travel advisor, shortest path algorithms to provide route selection routes from resource centers to points of incidents, weather information advisor, and resource allocation models that are responsive to concurrent emergency events over time.

MODEL VALIDATION

The Scenario

The MERMAIDS model was experimentally validated for usability using a realistic emergency response scenario. Consider the case scenario: a situation (hypothetical, but may be real) in which a potential dangerous chemical is released into the surround during a Home Coming football game at North Carolina A&T State University. Immediately, about 500 students are down unconscious, and another 200 are death. The University's emergency personnel had to notify the local emergency resources for help. The City and County Police, Firemen, Paramedics, Red Cross, FEMA, and other auxiliary services are available for the emergency response. The Department of Homeland Security dispatches the U.S. Air Force at Cherry Point, and Special Army Units from Fort Bragg, North Carolina. These military cohorts are trained on medical evacuation.

Heuristics Evaluation

The above scenario was used to conduct a heuristic evaluation of the MERMAIDS. A cohort of heterogeneous expert team was used. The team comprised of seven experts:. 1 Red Cross worker, 1 control officer from Federal Emergency Management Administration (FEMA), 2 emergency response police officers, 2 Firemen, and 1 retired Army personnel who has over twenty years of disaster relief operation. The experts were asked to use the MERMAIDS as a team to develop response plans for the case above. After the planning, the team was given a usability rating form and individuals were asked to independently rate the MERAMAIDS in terms of information management, information access, quality of information, ease of use, and representation of actual emergency planning scenarios. A Likert rating scale of very poor (1) to very good (5) was used.

Validation Results

The subjects' self evaluation data was summarized by calculating means and standard deviations. The comparison of mean differences was done by the student t-test using a level of significant (probability) of $\alpha = 0.05$. The null hypothesis is based on the assumption that an average Likert score of at least 3.5 will provide acceptable usability metric for each category of the MERMAIDS evaluation factor. The results are shown in Table 2.

Table 2. A Summary of the MERMAIDS Heuristic Evaluation.

MERMAIDS score metrics	Average score/ std	t_{value}
Information management	4.22(1.3)	3.94*
Information access	4.8(0.21)	3.185*
Information quality	**3.4(0.68)**	**1.737**
Emergency task representation	3.6(1.5)	579*
Ease of use	4.1(0.4)	2.86*

*Statistically significant at $\alpha = 0.05$, $t_{0.05}(7) = 1.895$.

The results in Table 2 indicate that all factors except information quality was not significant, indicating a concern for realistic incident database using actual emergency incident histories. As a prototype, most of the information used in the training module is obtained from one source, the fire service. This may be the cause of bias by the expert users who actually commented on the lack of their protocols in the training database. At this stage of the MERMAIDS design, we are concerned about information management, including access, and realism of information. We hope to extend the current databases to accommodate a wide range of emergency response management systems.

CHAPTER 4: CONCLUSION

Emergency situations, in general, often require distributed control because the agents involved are geographically dispersed. Some examples include the location of paramedics, police, fire stations, and so on. An operator monitoring a system for a potential terrorist attack or accident scene must have an accurate mental representation of the controlled system. Communication and information sharing in time and space are the basis for distributed decision-making by ERT staff. The MERMAIDS has been designed to contain decision-centric interface, which is not only useful for emergency information management, but has decision models to support response planning during emergency conditions.

The primary components of the HCI include incident database modules that allow the C2 operators to create and store incident characteristics. The resource management system allows the user to determine resource configurations when emergency conditions occur. The user interface allows the user a friendly interaction with the database, information display and visualization and for communication with field responders.

The current expert heuristic evaluation of the MERMAIDS is encouraging. The expert emergency C2 operators reacted favorably to the system, especially its application in planning emergency response under resource constraints. The evaluators also like the travel advisor that contains maps, weather conditions, and instructions on getting from location of resources to the incident site. The MERMAIDS also contains a training module for training first responders, which need to be expanded to include many training doctrines. This module helps the users to simulate team planning and collaboration decision-making during emergency. There is an on-going large-scale usability experiments planned for the MERMAIDS, as well as its enhancements with analytical algorithms to support better resource requirements for emergency event. The use of geographic information system is also being explored for use in enhancing real-time information for the travel advisor component. The MERMAIDS user's manual is shown in the Appendix section of this report.

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APPENDIX A

THE MERMAIDS USER'S MANUAL

The MERMAIDS software consists of the following main menu options:

- New Incident
- Notify
- Standard Operation Procedures (SOP)
- Command Structure
- Planning
- Operations
- Training
- Display Map
- Show Resources
- Get Directions
- Get Weather Conditions

Figure A1, shown below, is the main screen of the MERMAIDS. To activate any of the menu options, the user simply clicks on the button.

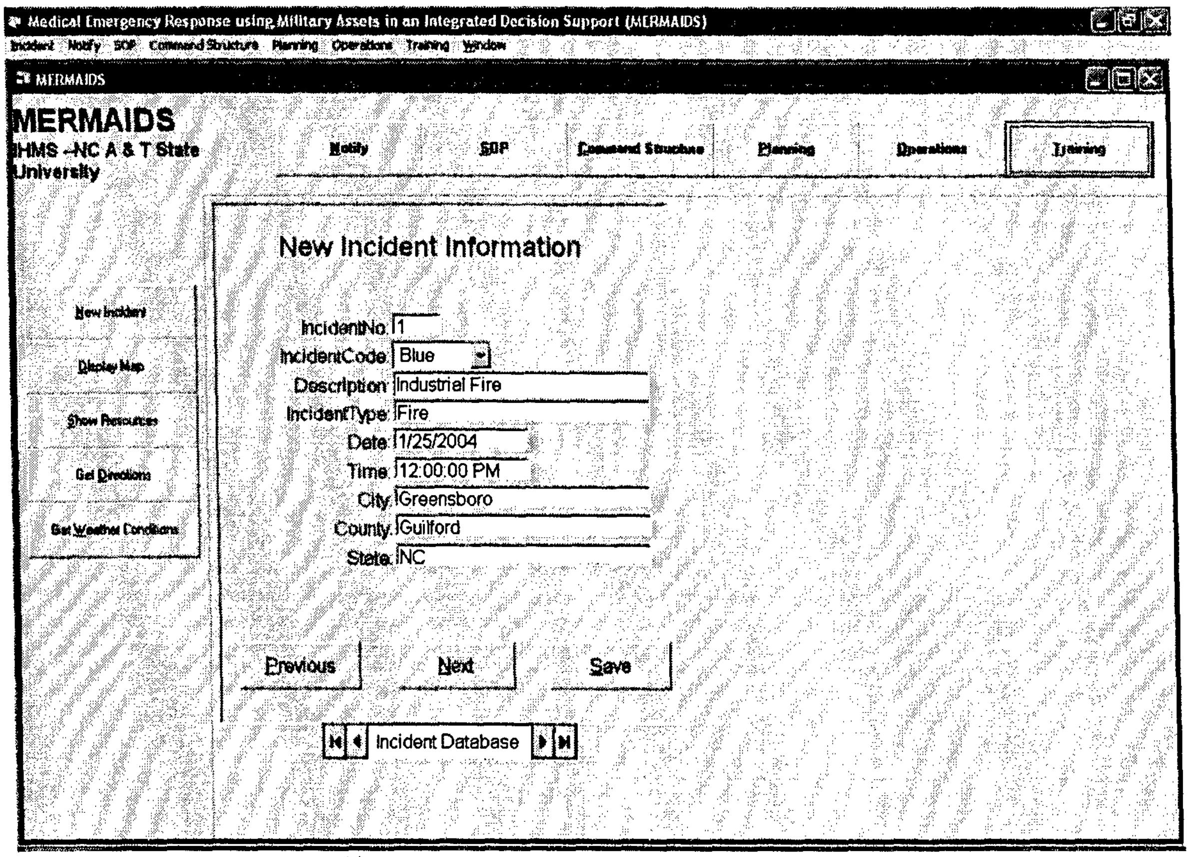

Figure A1. The MERMAIDS Main Menu.

The New Incident Menu

The New Incident menu allows you to enter information regarding the new incident. It also allows you to specify the severity of the new incident. The severity level is based on the color code used by the Department of Homeland Security (Exhibit A-1). The navigational buttons on the form allow you to save the new incident and navigate previous incidents.

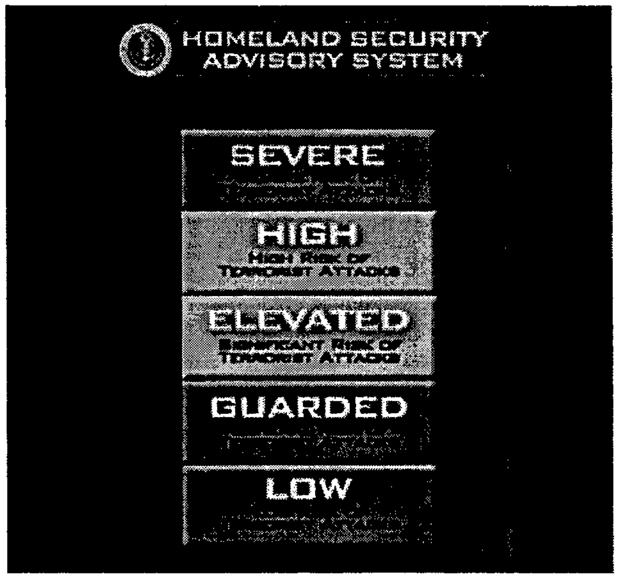

Exhibit A-1. Sample Emergency Color Codes used by the Department of Homeland Security.

The Display Map Menu

The Display Map Menu (Figure A2) shows the map of the area where the new incident is taking place. It allows you to pinpoint the location on the map and specify the severity of the incident. The MERMAIDS currently allows one incident at a time. This is done by clicking on the map the location of the incident. A flashing color coded circle appears where you click on the map. The color is based on the severity code you have selected when entering the information about the new incident.

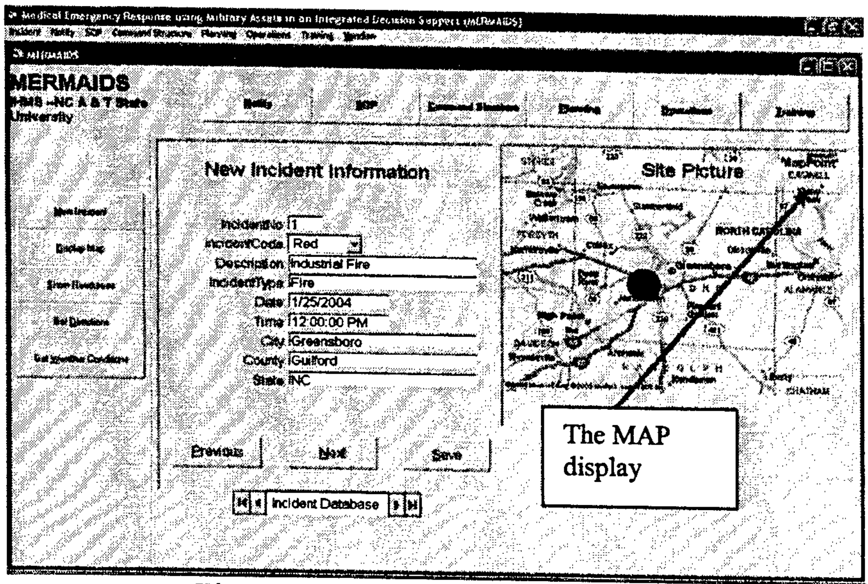

Figure A2. The Display Map Screen.

The Show Resources Menu

The Show Resources menu, shown in Figure A3, displays the location of the fire stations and paramedics for the area shown on the map. The visualization of the resources with respect to the current location of the incident allows the Command and Control (C2) center staff to quickly determine which resources to notify first. In Figure A3, the resources are shown in red and green.

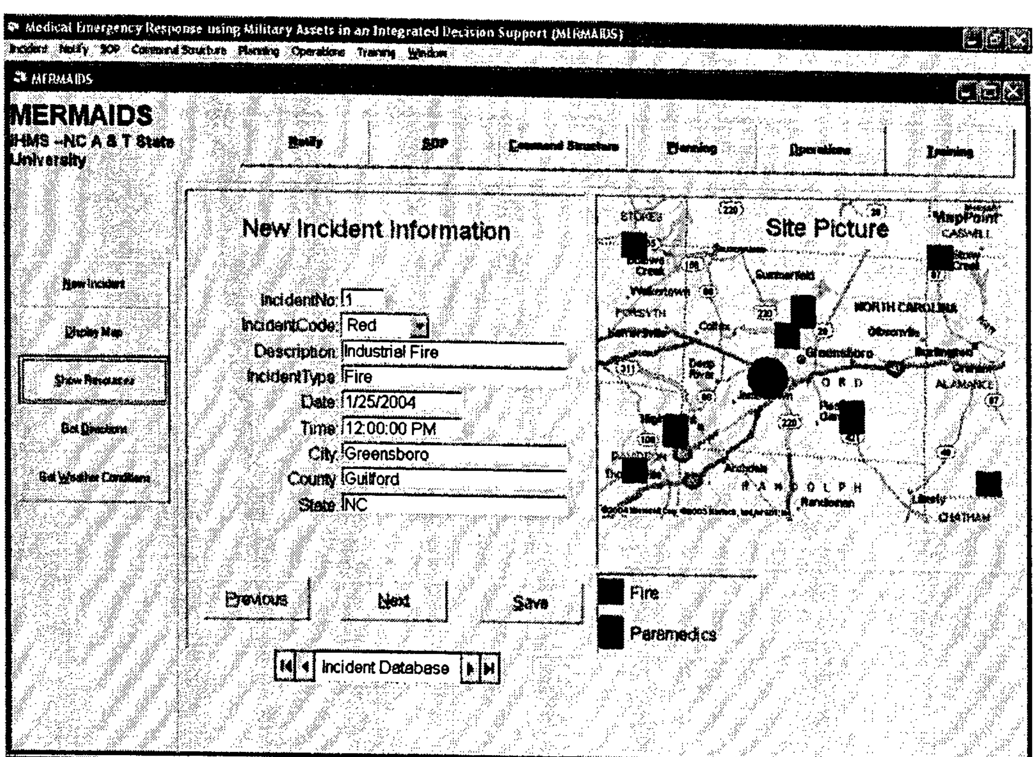

Figure A3. Show Resources Screen.

The Get Direction Menu

The Get Direction menu in Figure A4 allows the C2 staff to search for and give quick, directional advice to the field responders on each resource notified from their present location to the site of the incident. The menu uses the most active website information. In Figure A4, 'MAPQUEST' server is activated. The user simply specifies the information on the beginning and end addresses to the field responders.

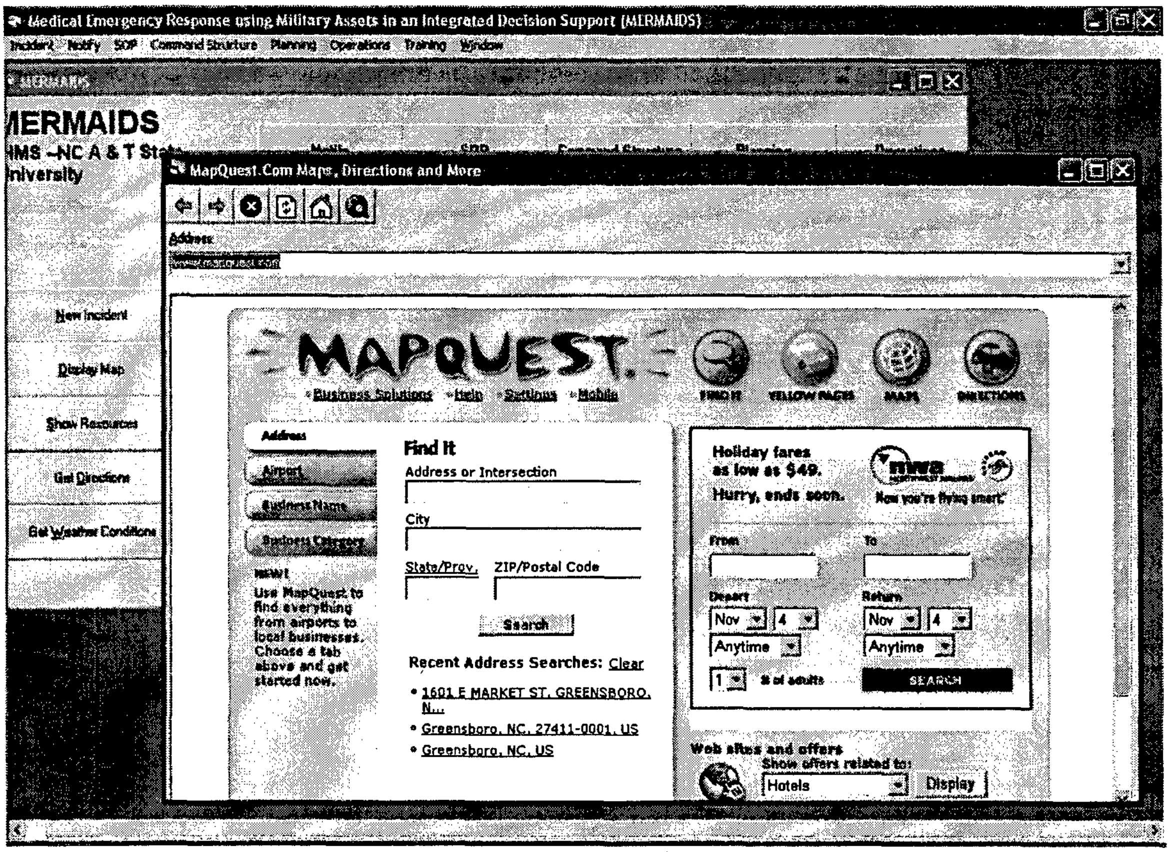

Figure A4. Get Direction Menu.

Get Weather Condition Menu

The Get Weather Condition menu (Figure A5) allows the C2 staff to get the current weather conditions for the area where the incident is occurring. This information is then communicated to the members of the emergency response team. It also helps in resource planning allocation. The weather condition is monitored throughout the duration of the incident.

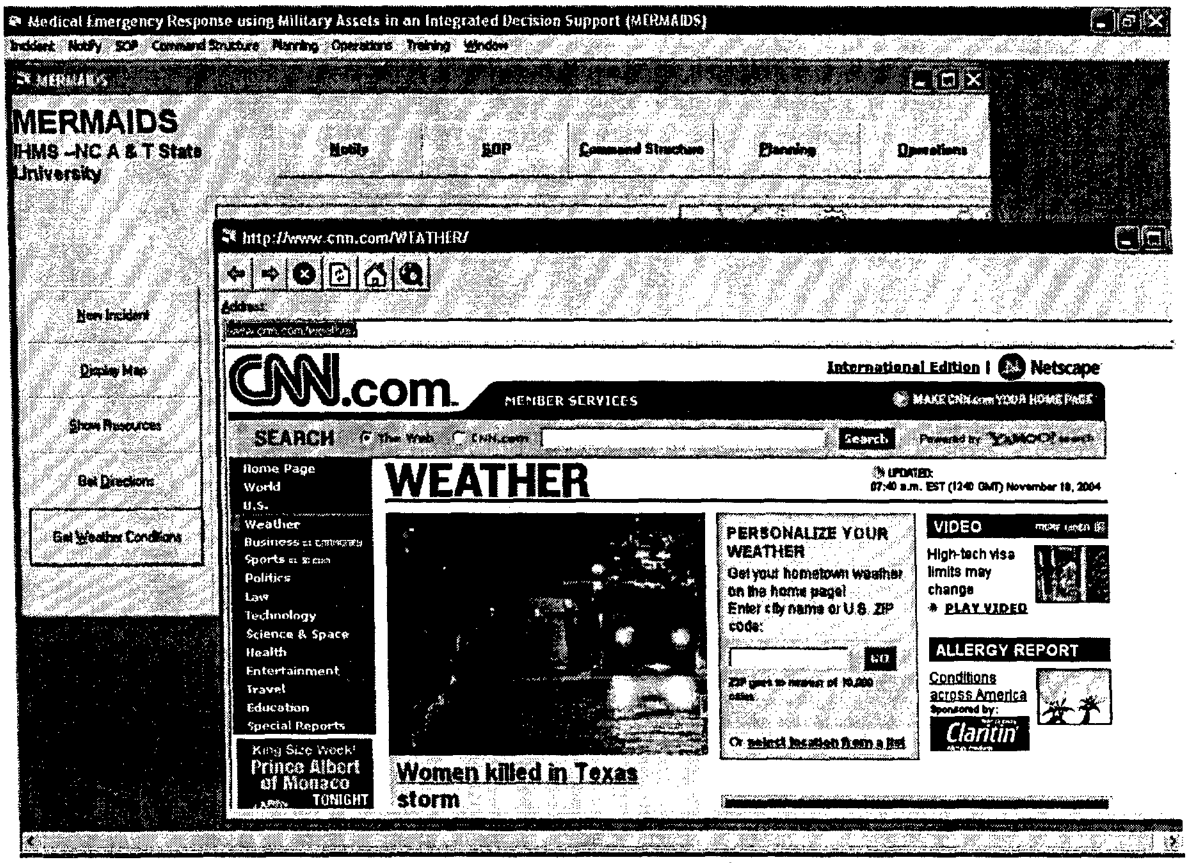

Figure A5. Get Weather Condition Menu.

Notification Menu

The Notification menu is used by the C2 staff to notify emergency workers out in the field of the nature of the incident. The notification form (Figure A6) displays whom to notify based on the severity of the incident, which was entered in the New Incident form.

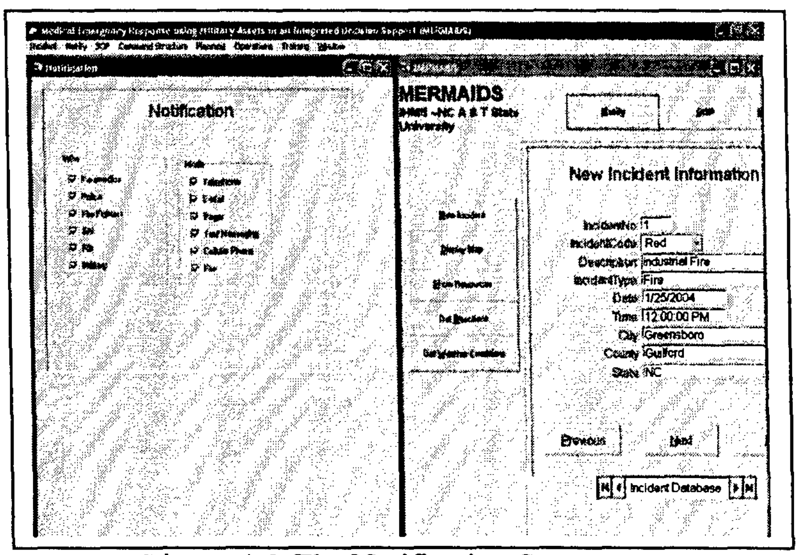

Figure A6. The Notification Screen.

The Standard Operation Procedure (SOP) Menu

The Standard Operation Procedure menu (Figure A7) is activated by clicking the SOP button. As a result of this action, a submenu is displayed on the lower left side of the screen. The submenu lists the organization with the SOP available. By clicking on any of the submenu buttons, you will activate the website of the agency corresponding to that submenu button. For example, Figure A7 below shows the website of the United States Army. The user can then navigate the web for the SOP of the Army. There is an opportunity to reduce the information search by compiling each organization SOP into a formatted database.

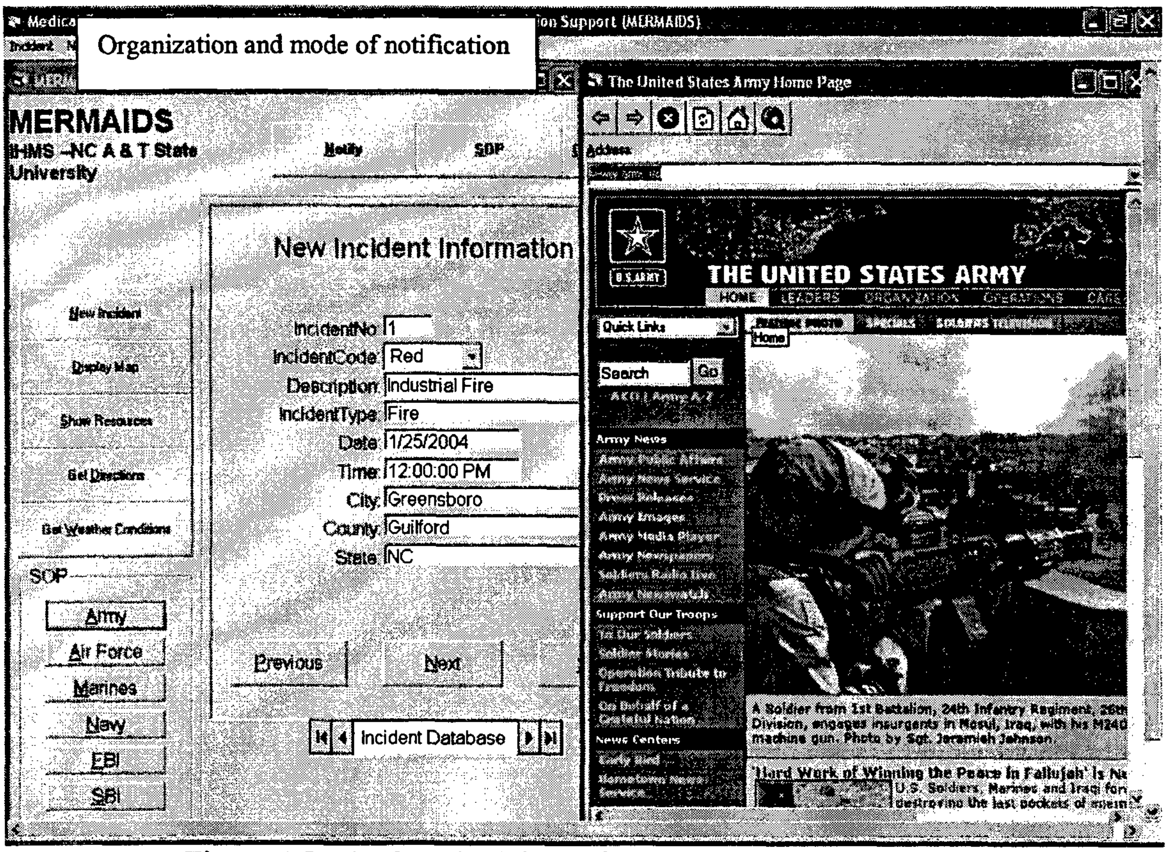

Figure A7. The Standard Operation Procedures (SOP) Screen.

The Command Structure Menu

The Command Structure menu (Figure A8) displays, in a text format, the command structure based on the incident attributes and scope. The command structure is simply a reporting hierarchy to be followed when an emergency incident occurs. The incident attributes consist of the incident type and the severity of the incident. The scope defines the extent of the incident. The scope may be local, state or national. Once the incident attributes and scope have been selected, the user then clicks the "Display Command Structure" button. Clicking this button displays the command structure. As shown on the sample screen, we have a car accident incident. The reporting authorities are the police, the fire department, and the emergency medical services (EMS), in that order.

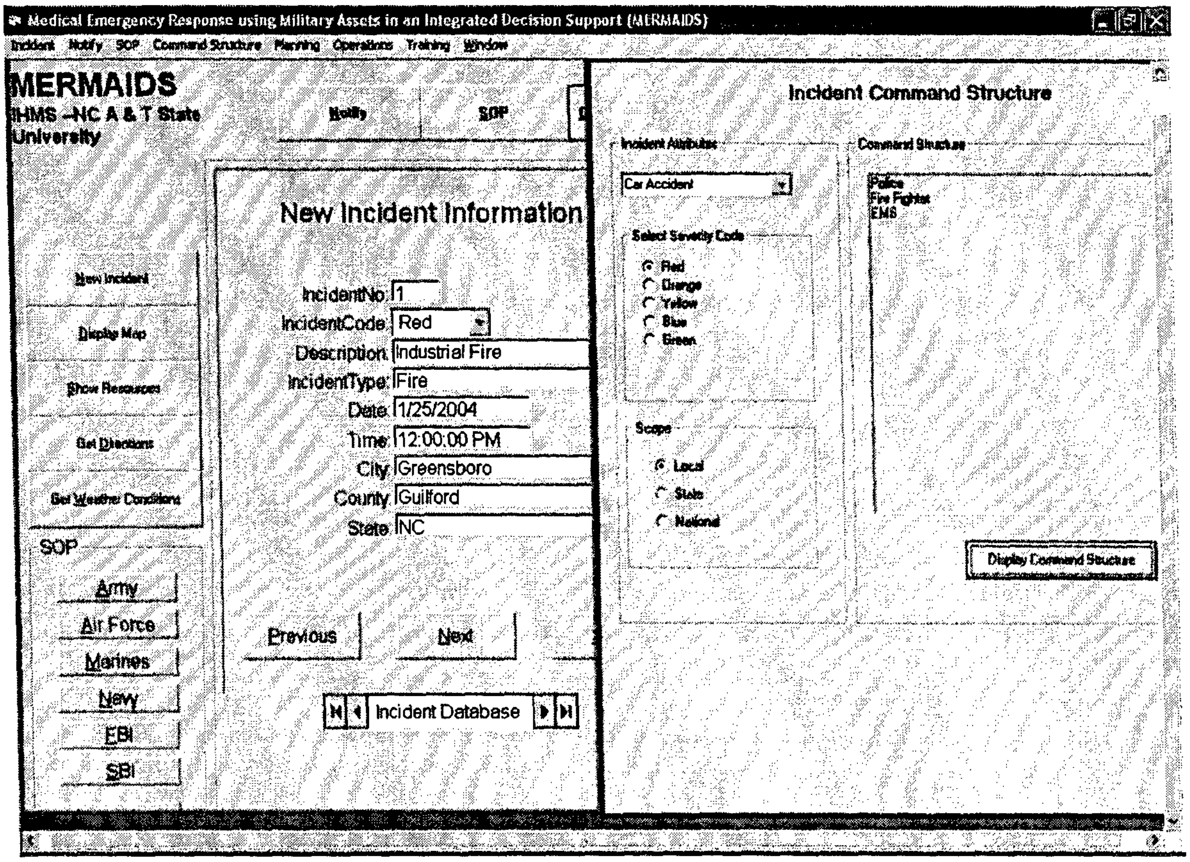

Figure A8. The Command Structure Menu.

The Planning Menu

The planning menu has two submenus:

- Create Operational Objectives
- Create Incident Action Plan

Create Operational Objective Menu

The Create Operational Objectives submenu (Figure A9) allows the C2 staff to develop the objectives required to carry out the emergency response to the incident. Other information required for the objective attainment is weather condition and safety conditions of the incident environment.

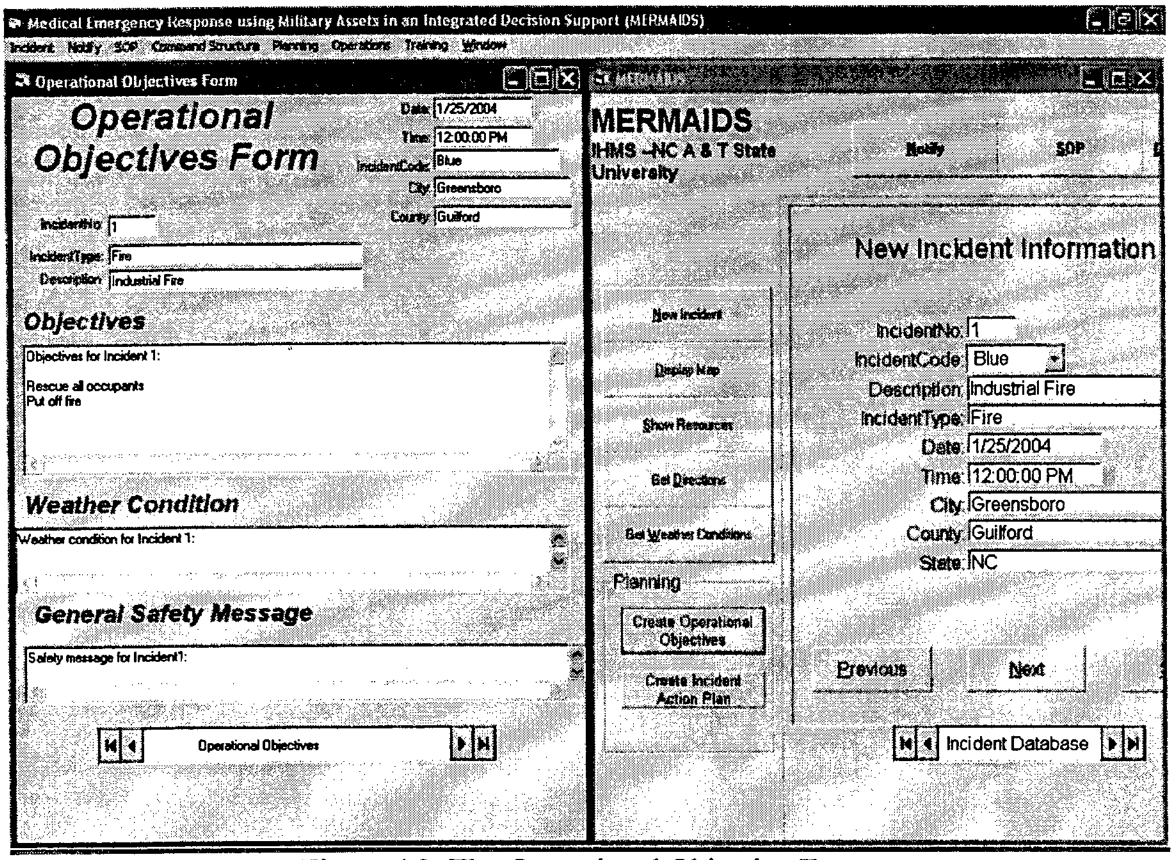

Figure A9. The Operational Objective Form.

Create Incident Action Plan

The Create Incident Action Plan form (Figure A10) allows the user to document all the necessary action plans for the incident. The action plans for previous incidents may also be viewed and adopted for similar incidents. The left hand side of Figure A10 shows the incident action plan form.

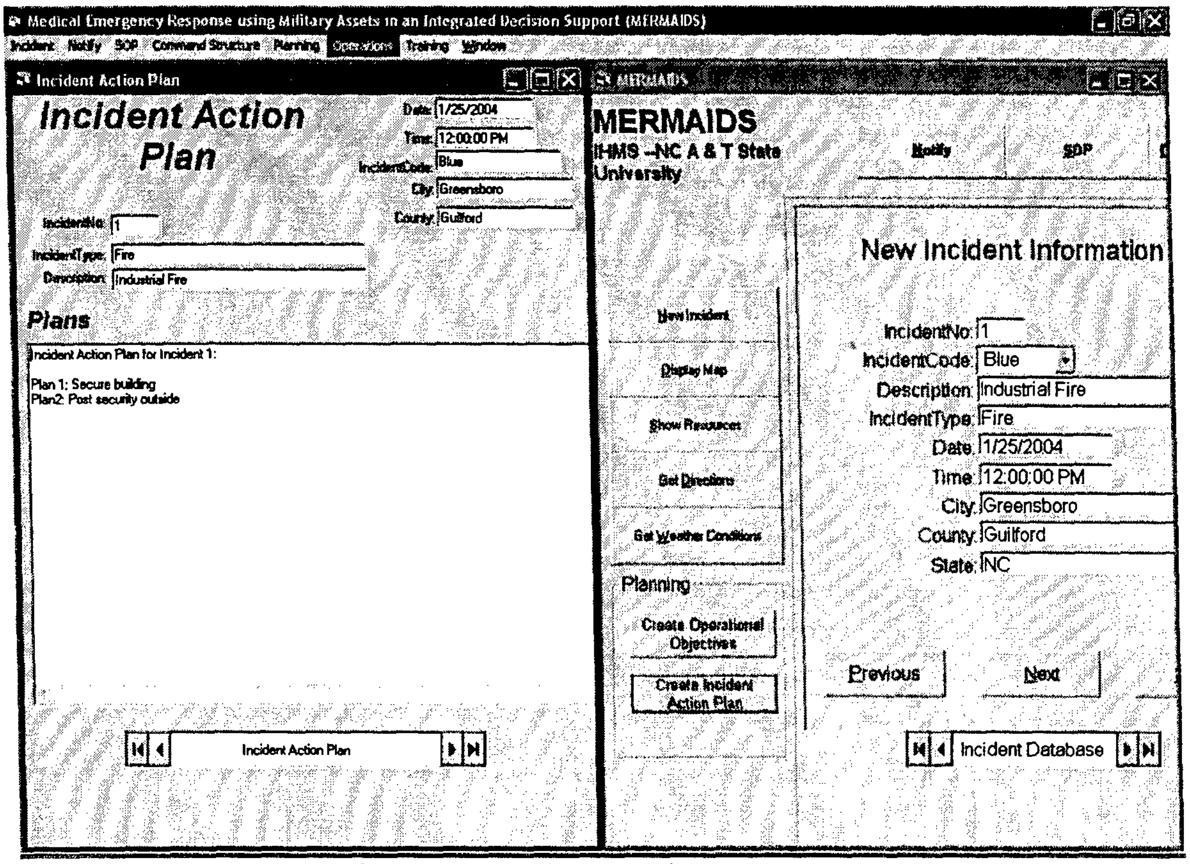

Figure A10. Incident Action Plan Menu.

The Operations Menu

The operations menu has two submenus:

- Resource allocation
- Triage Management

<u>Resource Allocation</u>

The Resource Allocation submenu (Figure A11) allows the user to assign resources to the incident based on availability of those resources. In the case of multiple incidents occurring simultaneously, the submenu allows the user to dynamically allocate the resources based on the severity of the incidents.

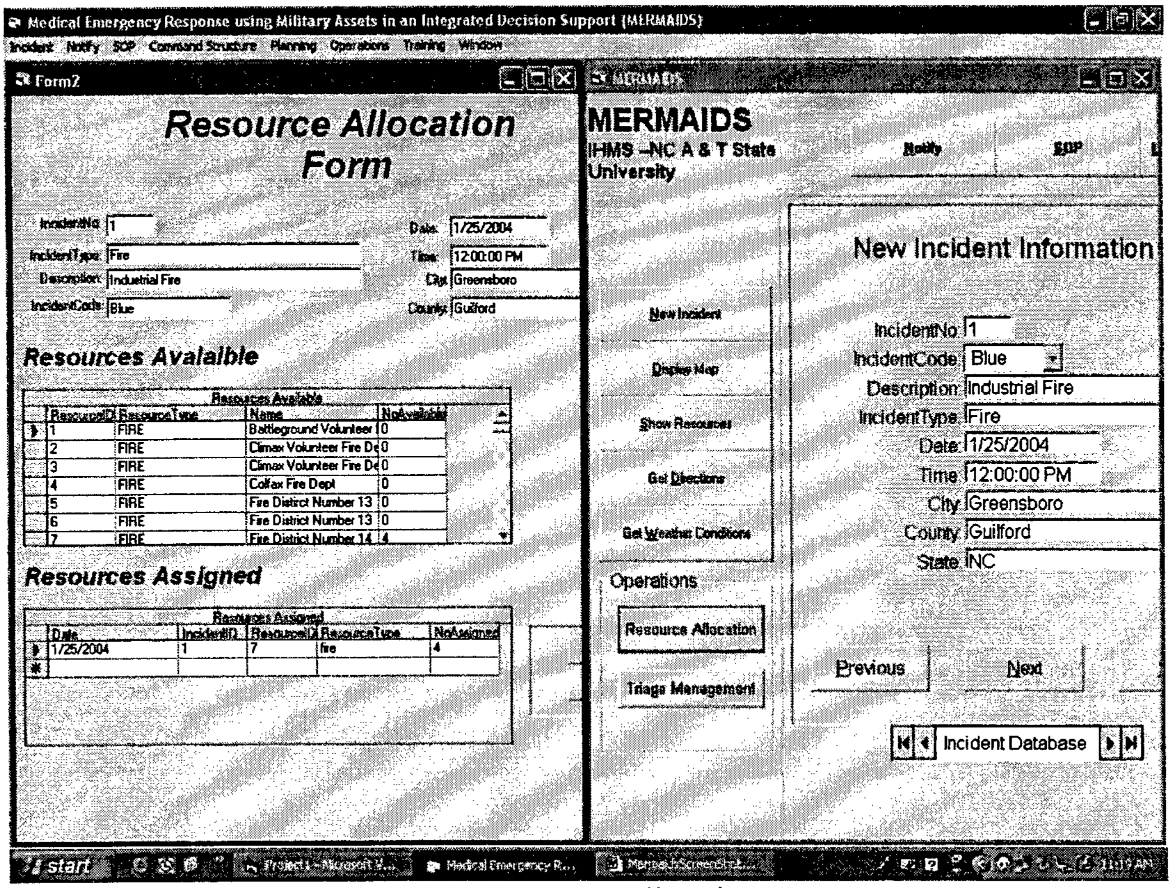

Figure A11. Resource Allocation Menu.

Triage Management

The Triage Management submenu (Figure A12) allows the user to record the number of casualties (death, injured, etc.) during an incident. The Triage Management screen displays the summary statistics for the incident and displays the graphical representation of the summary statistics. In the case of multiple incidents occurring simultaneously, the Triage Management screen displays the summary statistics for each incident as the user moves from one incident to the other.

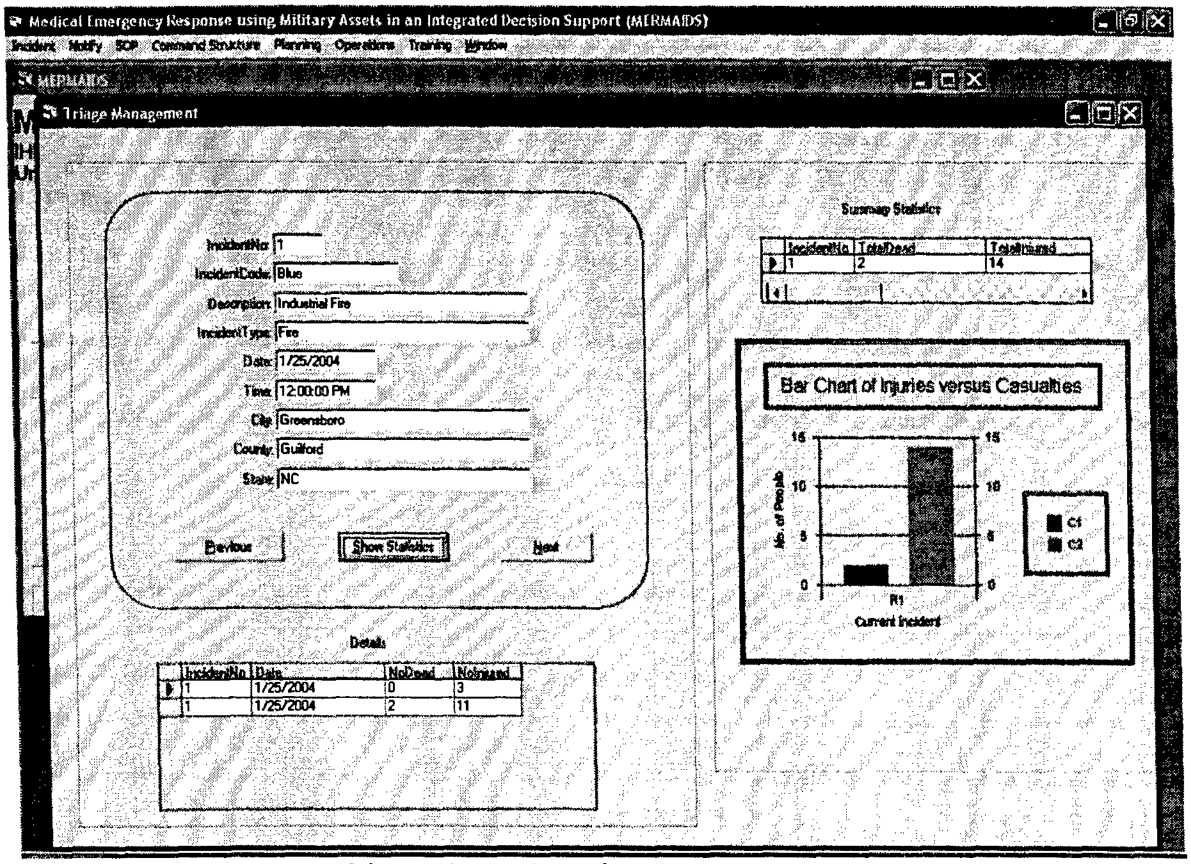

Figure A12. The Triage Management Screen.

The Training Menu

The Training Screen (Figure A13) provides the user different scenarios of emergency incidents. The user then goes through six (6) different lessons. Note that other lessons can be added. By clicking the "Get Scenario" button, an emergency scenario is randomly presented. To select a lesson the user clicks on the lesson icon. This activates the Microsoft Word read only lesson document, which consists of activities the user must undergo. The training screen also enables the user to perform all the functions described earlier in this manual.

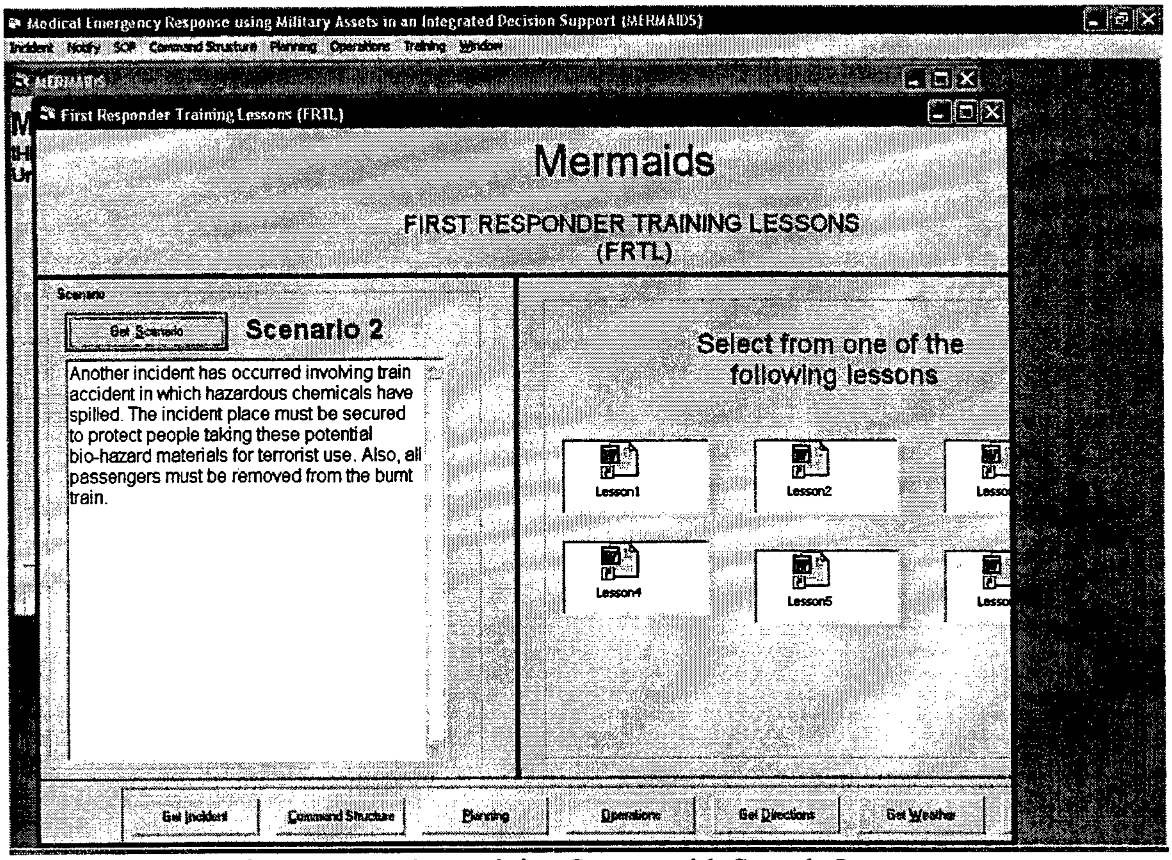

Figure A13. The Training Screen with Sample Lessons.